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ABSTRACT

Almost all experimental investigations on concepts of time (T), distance (D) and velocity (V) since 1946 have been based on the Piagetian theory. However, there are several controversial points in Piaget's investigations. In the experiment described in this paper, developmental changes of concepts concerning relation of T, D, and V were examined using 148 children from 4- to 10-years-old and 20 undergardaute students, with the aim of addressing the controversy in Piaget's investigations. Results of these investigations include: (1) almost all children over 5 years of age could understand the proportional relation between D and T, and V and D through concrete operation, though they could not verbalize the reasons for their understanding; (2) it was difficult for young children to understand the inversely proportional relation between V and T even through concrete operations, but, the verbalization of reasons developed rather smoothly and rapidly after age 8; (3) in young children under 6-and-a-half-years-old, all relations between two variables seemed to be proportional and they seemed to pay little attention to the third constant variable; (4) over 8-years-old, most children correctly understood two proportional relations and one inversely proportional relation; and (5) it is not clear if children over 9 had the intercorrelational concept among three variables. (CW)

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July 13, 1987

CONCEPTS ABOUT RELATIONS AMONG TIME, DISTANCE AND VELOCITY
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The first systematic experimental investigations on concepts of time, distance and velocity were carried out by Piaget (1946a, b). Since then almost all investigations in this area have been based on them. However, several controversial points in Piaget's investigations remain unsolved. That is, (a) there was no symmetry among the three experimental situations in which the developmental processes of three concepts were examined; (b) concepts concerned with intercorrelations of time, distance and velocity, that is, $V(\text{velocity})=D(\text{distance})/T(\text{time})$, $D=V \cdot T$, and $T=D/V$, were rarely directly investigated; and (c) in most of his experimental situations, it was impossible to distinguish conceptual and perceptual judgments.

In the experiment described in this paper, developmental changes of concepts concerning relations of time, distance and velocity were examined using children from 4 to 10 years old, with the aim of trying to conquer the problems mentioned above.

Method

Subjects. The subjects numbered 148 children who ranged in age from 4 years and 11 months to 10 years and 8 months and 20 undergraduate students. The subjects were evenly divided between males and females.

Apparatus. A runner (10 cm X 10 cm) could run on a rail of 149 cm-length at a speed of 1 to 30 cm/s. One of three toy trains of 10 cm-length, a green superexpress, a red express, or a blue local train, could be set on the runner. Speeds of the three trains were regulated to be 25 cm/s, 10 cm/s, and 4 cm/s, respectively. By the right end of the rail, there was a tall, brown toy station of 10 cm-width, which was the starting point of trains, and there were three short toy stations also 10 cm-width, white, gray, and black, at the distances of 20 cm, 50 cm, and 125 cm, respectively from the tall brown one. Besides, there was a box with three buttons, red, blue, and yellow. When any one of the buttons was pushed, the runner could begin to move and a whistle could begin to blow. The durations of the blowing were set to be 2 s for the red one, 5 s for the blue one, and 12.5 s for the yellow one. A personal computer (NEC, PC-9801-VX) controlled speeds and destinations of the runner, the whistle's durations, whether the runner began to move or not when one of the buttons was pushed, and whether a whistle began to blow or not when one of the buttons was pushed. The runner could be returned to the starting point by pushing a return key in the personal computer.

Stimulus conditions. All six sessions were carried out for each subject. Session DV; judgements about D were asked, when V increased

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(or decreased) with a constant T ($D=(T)V$). Session TV; judgments about T were asked, when V increased (or decreased) with a constant D ($T=(D)/V$). Session TD; judgments about T were asked, when D increased (or decreased) with a constant V ($T=(1/V)D$). Session VD; judgments about V were asked when D increased (or decreased) with a constant T ($V=(1/T)D$). Session VT; judgments about V were asked, when T increased (or decreased) with a constant D ($V=(D)/T$). Session DT; judgments about D were asked, when T increased (or decreased) with a constant V ($D=(V)T$). In Sessions DV and VD, three combinations of values in T , V , and D were used, that is, 5 s, 4 cm/s, and 20 cm; 5 s, 10 cm/s, and 50 cm; 5 s, 25 cm/s, and 125 cm. In Sessions TV and VT, 12.5 s, 4 cm/s, and 50 cm; 5 s, 10 cm/s, and 50 cm; 2 s, 25 cm/s, 50 cm. In Sessions TD and DT, 2 s, 10 cm/s, and 20 cm; 5 s, 10 cm/s, and 50 cm; 12.5 s, 10 cm/s, and 125 cm.

Procedure. The six sessions were carried out in one of the following six orders at random for each subject: DV, TV, TD, VD, VT, DT; TV, TD, VD, VT, DT, DV; TD, VD, VT, DT, DV, TV; VD, VT, DT, DV, TV, TD; VT, DT, DV, TV, TD, VD; DT, DV, TV, TD, VD, VT. The last three sessions were carried out about a week after the first three sessions. There were rests of about 15 minutes between every two sessions in each experimental day.

Procedure in Session DV were as follows: (a) The experimenter (E) showed a subject (S) that the three trains ran one by one without whistles and asked him/her to discriminate differences in their velocity and to tell the order of their velocity. (b) E showed S three short stations and asked him/her to tell the order of distance from the tall brown station. (c) E blew a whistle (5 s) by pushing the blue button and said that after that the trains would run during this whistle's blowing and that the duration of it would be always the same. (d) E showed S that the red train (10 cm/s) ran just to the grey station with the whistle (5 s) by pushing the blue button. (e) E asked S to guess to which station the green train (25 cm/s) would run with the whistle of the same duration. (f) After S answered, E asked S why he had guessed so. (g) E showed S the green train ran to the black station by pushing the blue button. (h) E asked S to guess to which station the blue train (4 cm/s) would run with the whistle of the same duration. (i) After S answered, E asked S why he had guessed so. (j) E showed S the blue train ran to the white station (20 cm). (k) E asked S whether the durations during which the three trains had been running were all the same or not. If S's answer was "Not the same.", E added a question which train had run during the longest duration and which train had run during the shortest duration. (l) E made sure that S remembered exactly the order of speed among the three trains. (m) E made sure that S could indicate exactly the order of distance from the tall brown station of the three short stations.

Other sessions were carried out in the same way, except T , D , and V were exchanged with one another.

Thus in this experiment, T , D , and, V as variables were set to be as symmetrical as possible, and to be as concrete in the same degree as possible.

Results and discussion

As one child of 5 years and 6 months old could not discriminate

differences among the three velocities and among the three durations, the data of 147 children were analyzed. All children were ranged in age. Mean age of the first 10 children was calculated and a percentage of children who could answer correctly in both questions of (e) and (h) in the procedure, who could answer correctly only in one of the two questions, and who could not answer correctly at all were calculated. Marks $\circ$, Δ , and $\times$ were assigned to them, respectively. Then, for 10 children from the 2nd to the 11th the same calculations were done, and the same calculations continued for 10 children from the 138th to the 147th. These results are shown at the bottom of Figs. 1, 2, 3, 4, 5, and 6 for each session.

Reasons given as answers in (f) and (i) of the procedure were classified into five categories. No answer, "I don't know.", or answers which did not refer to any qualities of T, D, and V at all were judged to belong to Class 1. Answers which referred to the quality of independent or dependent variable were classified into Class 2; for example, "Because the green train is very fast." referred to the quality of the independent variable in Session DV. E always added another question after the answer belonging to Class 2. For example, "Why is the black station good, when the green train is very fast?". If S could add the quality of dependent or independent variables, for example, "Because the black station is far.", which referred to the quality of the dependent variable in Session DV, his reason was classified not as Class 2 but as Class 3. Class 4 indicated an answer which referred to the qualities of both dependent and independent variables at the same time; for example, "Because the green train is fast and the black station is far." in Session DV. An answer which referred simultaneously to the qualities of dependent, independent and constant variables belonged to Class 5. For example, "Because, as duration is constant, the fastest train can reach the farthest station." in Session DV. Percentages of these reasons were also calculated in the same way and were shown in the middle of the figures.

Percentages of responses for the question (k) in the procedure are shown in the top of the figures. Responses were classified into four. Mark $\circ$ means that S recognized that a constant variable had been constant. Mark V-large $\Rightarrow$ T-large, for example, means that S answered that T, a constant variable, had not been constant, and that the fastest green train had taken the longest time and the slowest blue train had taken the shortest time. Mark $\times$ means that S had no answer, or could not recognize that a constant variable had been constant and his answer about changes of the constant variable was not systematic.

In Figs. 1 to 6, percentages of these measures in the undergraduates were added.

The main results were as follows:

(a) Almost all children over 5 years of age could understand the proportional relations between D and T, and V and D through concrete operations, though they often could not verbalize the reasons for their understanding.

(b) It was very difficult for young children to understand the inversely proportional relations between V and T even through concrete operations. But in this case, the verbalization of reasons developed rather smoothly and rapidly after 8 years old. It seems that even through

concrete operations children need to be conscious of two qualities which are inversely proportional in order to understand the inversely proportional relations.

(c) In young children under 6 and a half years old, all relations between the two, D and T, V and D, and even V and T, seem to be proportional. They seem to pay little attention to the third constant variable.

(d) Over 8 years old, most children understood correctly two proportional relations and one inversely proportional relation at least through concrete operations. But they also seem not to pay enough attention to the third constant variable. Although the experimenter repeated that the constant variable was constant in each trial, they often could not recognize that it had been constant. Their answers to the questions about constant variables seem to be affected by the concept formation of the inversely proportional relation between T and V.

(e) It is not clear if children over 9 years old had the intercorrelational concept among the three variables, because there were only a few answers belonging to Class 5. However, at least they seem to be ready to learn it because most of them recognized easily that a constant variable had been constant.

Analyses about relations among answers of three kinds of questions in a certain session and among answers in the six sessions have not yet been carried out.

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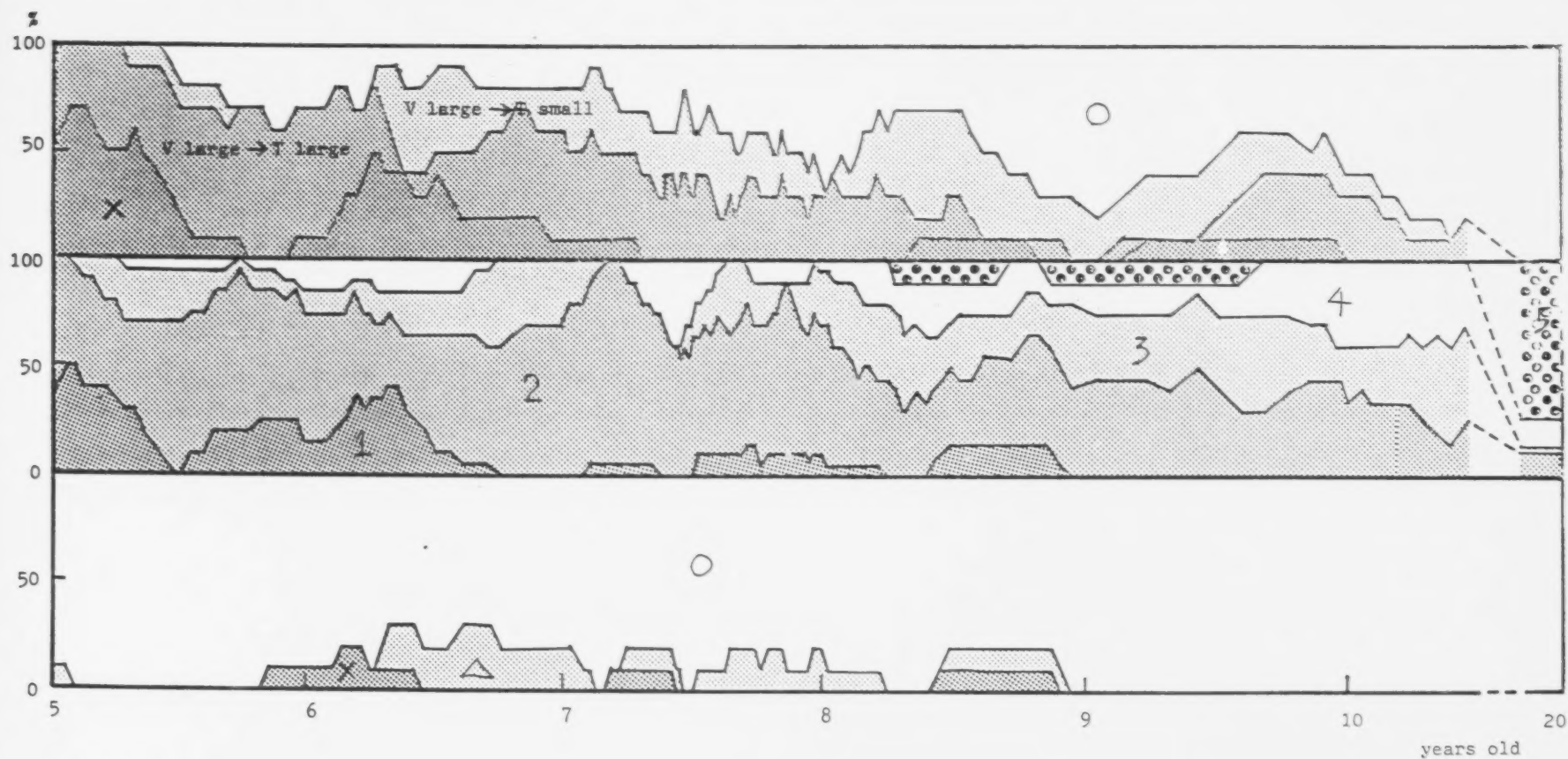


Fig. 1. Development of intercorrelational concepts concerned with $D=(T)V$ (Session DV).

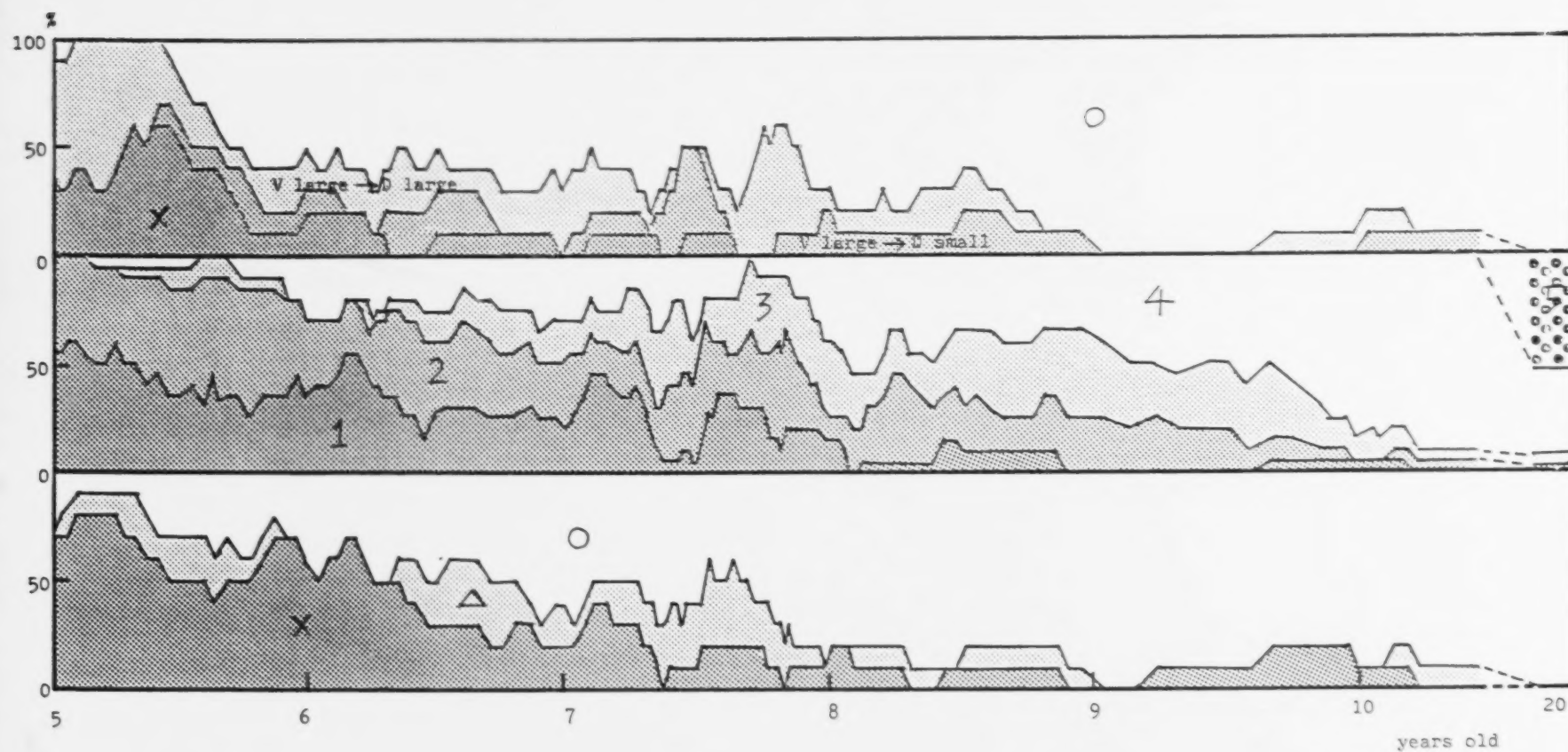


Fig. 2. Development of intercorrelational concepts concerned with $T=(D)/V$ (Session TV)

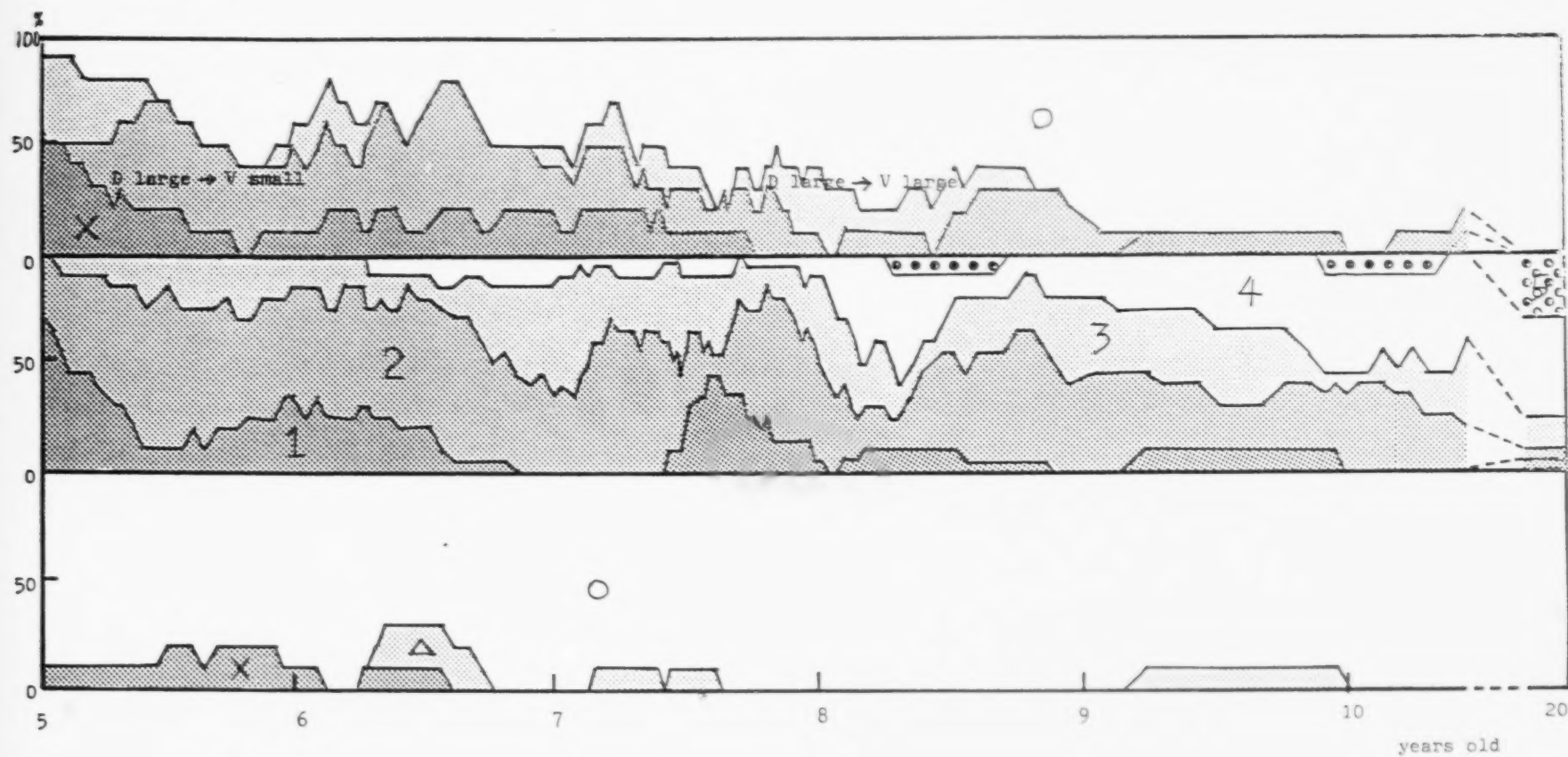


Fig. 3. Development of intercorrelational concepts concerned with $T=(1/V)D$ (Session TD)

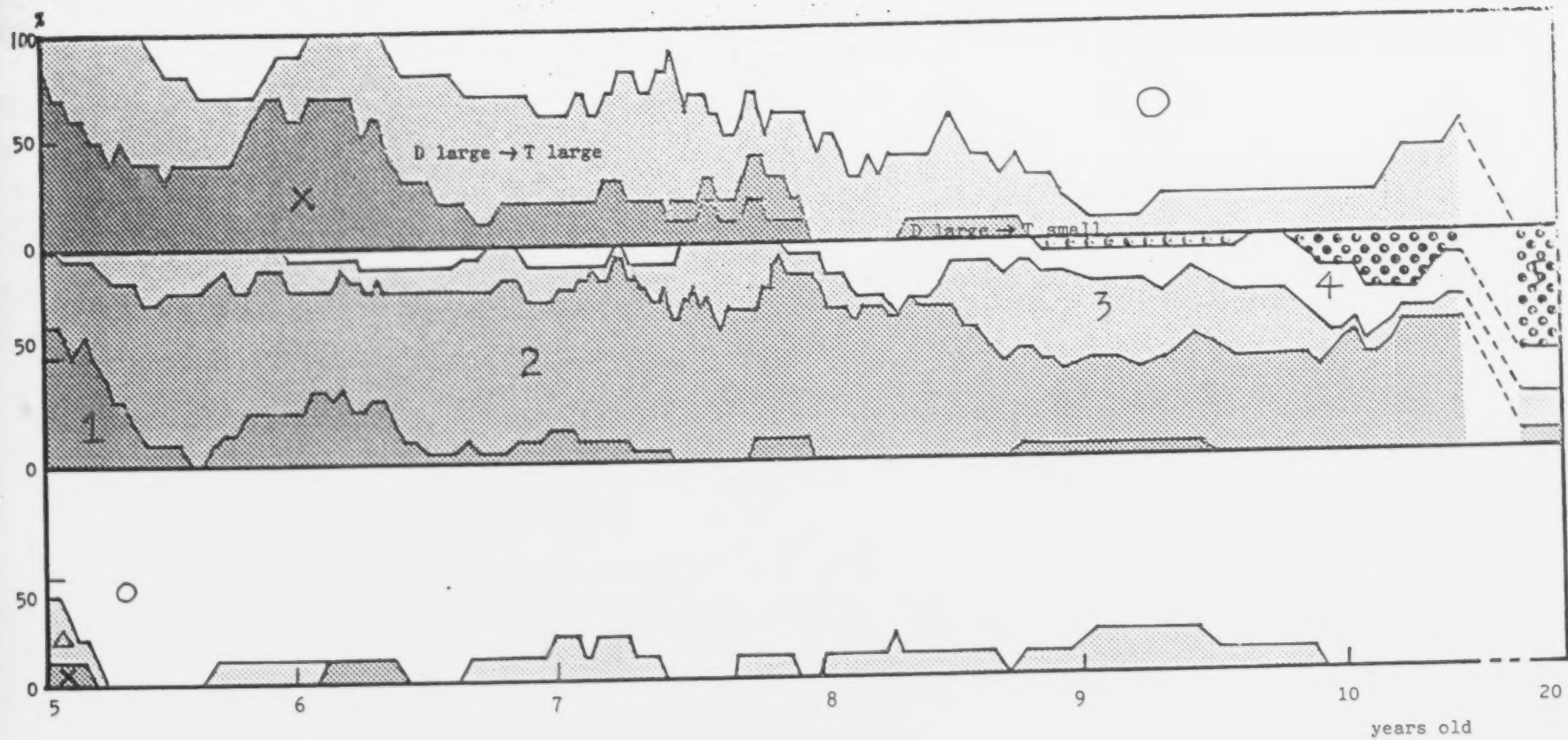


Fig. 4. Development of intercorrelational concepts concerned with $V=(1/T)D$ (Session VD)

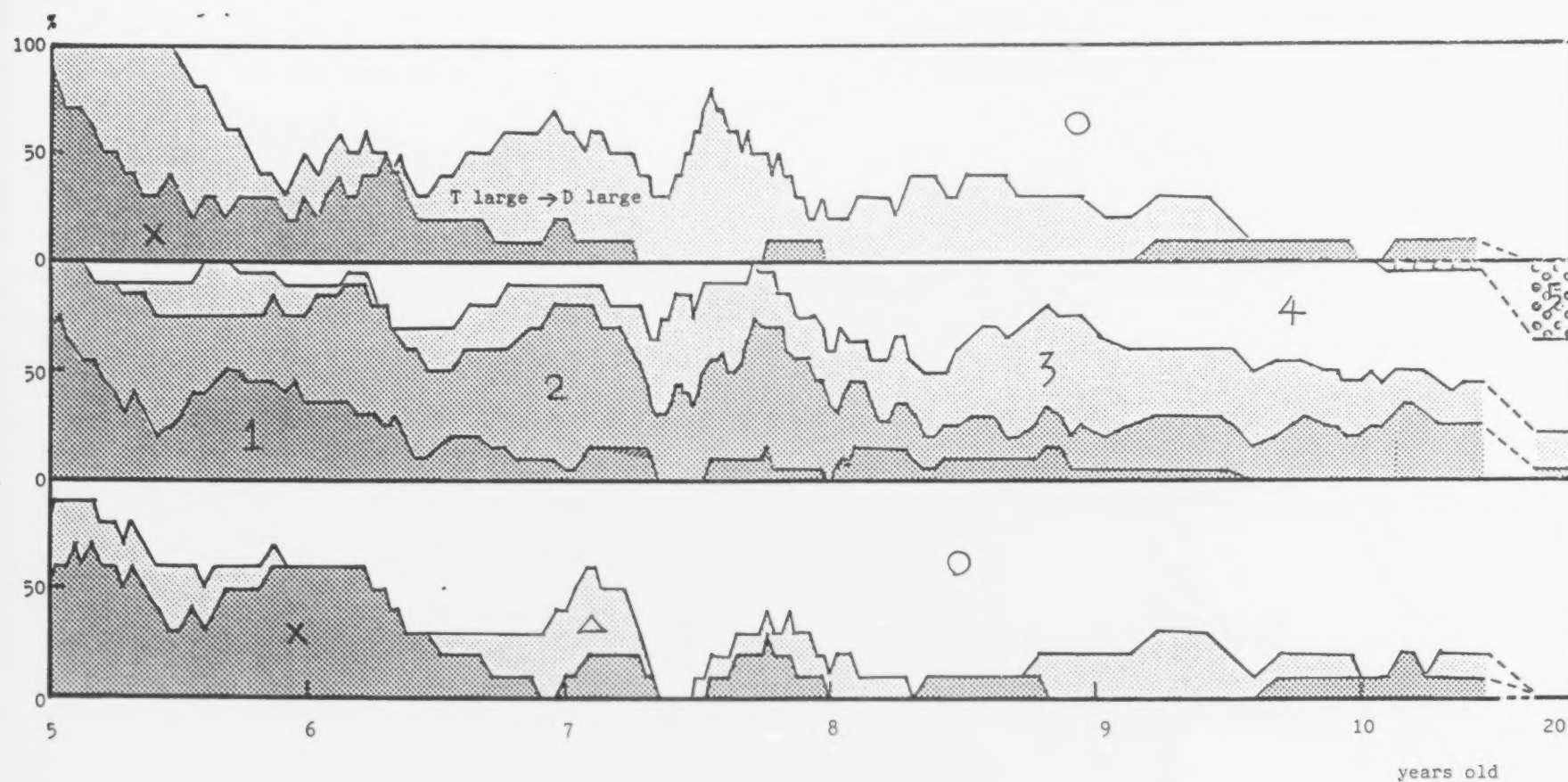


Fig. 5. Development of intercorrelational concepts concerned with $V=(D)/T$ (Session VT)

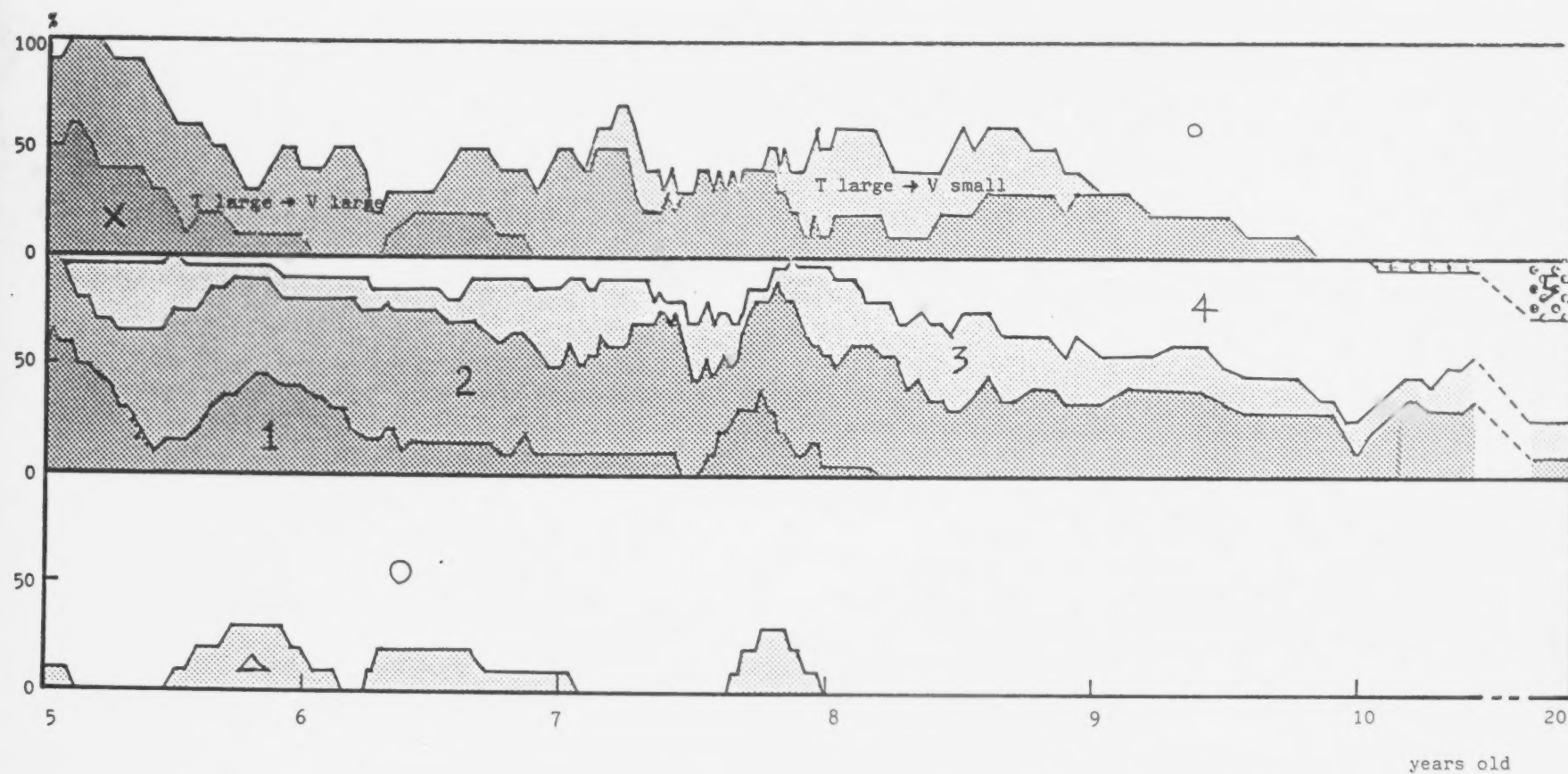


Fig. 6. Development of intercorrelational concepts concerned with $D=(V)/T$ (Session DT)